US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

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INFRARED MEASUREMENTS OF VEHICLES AND WEAPONS

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1. SCOPE. This TOP describes techniques and instrumentation for measuring infrared (IR) radiation during development and production tests of military ground vehicles and weapons. Such measurements are made to determine IR signatures of vehicles and temperatures of weapon tubes during a firing program. Graphs and diagrams are presented to indicate typical measurements but are not intended to represent a particular test firing or evaluation.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

ITEM	REQUIREMENTS
Vehicle test course	As applicable for operation of wheeled or tracked vehicles at full speed (See TOP 1-1-011.[1])

*This TOP supersedes TOP 2-2-812 dated 18 July 1979.

Approved for public release; distribution unlimited.

[1]TOP 1-1-011, Vehicle Test Facilities at Aberdeen Proving Ground, 6 July 1981.

ITEM (Cont'd)	REQUIREMENTS (Cont'd)
Open area	Large enough for test vehicle to fill field of view of radiometer; background as required in test requirements
Firing range	As applicable to weapon under test
Digital conversion facility	As applicable to weapon under test

2.2 Instrumentation.

ITEM	MAXIMUM PERMISSIBLE ERROR OF MEASUREMENT
*IR calibrated imager (such as Inframetrics 210)	Capability of measuring apparent temperature at wavelengths of 3 to 5 or 8 to 12 micrometers to ±0.1° C
*Army tactical IR sight (such as AN/TAS-4 or AN/TAS-6)	N/A
Measuring device for ambient conditions (psychrometer, temperature, relative humidity)	±0.1°C
Pyranometer (such as Epply with solar insolation)	±2%
*Blackbodies(2) 12 x 12 in.	±0.1°C
Standard meteorological setup (ASL detachment)	As required
3/4-in. standard U-matic cassette recorder	N/A

ITEM (for optional tests)	MAXIMUM PERMISSIBLE ERROR OF MEASUREMENT*
IR radiometer	Capability of measuring apparent temperature in wavelength regions of 2 to 20, 3 to 5, and 8 to 14 micrometers to ±0.1° C
Spectral radiometer measuring equipment	±0.02 mW/(cm^2 x sr x um)
Transmissometer	

*Individual test sites using this equipment for IR signatures would need to submit these items to a central image evaluation facility.

3. REQUIRED TEST CONDITIONS.

3.1 Planning. Plan each IR measurement project based on the following considerations:

3.1.1 Vehicles. Vehicle exhaust outlets and grilles (to include vehicle exhaust if requested), radiators, tires, suspension systems, heating systems, NBC systems, and exposed metal surfaces (especially where warmed by engine heat through operation or by solar heating) emit IR radiation and permit detection of the vehicle by sensor-directed weapons or surveillance systems. IR measurements are made of vehicles to assess their detectability and to identify temperature variations (ΔT) that could make the vehicle vulnerable to land and airborne heat-seeking weapons. Consideration can then be given to shielding the hot spots or redesigning to suppress the IR radiation.

Personnel heaters or on-board auxiliary generators create signatures and are considered to be IR sources in addition to the basic vehicles. Personnel heaters shall not be used during IR signature tests, unless directed otherwise.

3.1.2 Weapons. IR emissions from weapons are measured primarily to determine at a distance the increases in weapon-tube temperature as a result of a high rate of fire. This is done to determine the temperature at which cookoff can occur (requires accurate evaluation of emissivity).

3.2 Checklist. Prepare a test operations checklist similar to the guide in Appendix A.

3.3 Vehicle/Weapon Condition. Check the vehicle or weapon condition as appropriate in accordance with the list in Appendix B. Add to the list other parameters of interest as necessary.

3.4 Instrumentation. Check out and set up instrumentation as required for each subtest, and ensure proper calibration.

3.5 Test Controls.

a. IR signature tests will normally be conducted under weather conditions that typify the season and geographic location under investigation (snow-arctic, sand-desert, high humidity and heat-tropics, trees).

b. Signature data will be collected during both diurnal and nocturnal periods. For diurnal tests the effects of solar radiation shall be considered as part of the overall signature, and monitored in terms of solar load (including other standard weather conditions) during the test. The standard set of signature data will contain data taken on days with a high solar load and on nights whose preceding days had low solar loads. The range in solar loading will be consistent with the season and the geographic location that the test is intended to represent.

c. Each test item will be tested in the configuration normally employed during field use, with all components and accessories mounted and operating. It will be painted as required for combat and be tested free of mud, dust, snow, ice, frost, and water.

4. TEST PROCEDURES.

4.1 Measurements for IR Signatures of Vehicles. Table 1 shows the standard vehicle operating conditions under which the basic signature data are obtained in the radiometer tests, temperature tests, and imagery analysis described in paragraphs 4.1.1, 4.1.2, and 4.1.3.

4.1.1 Radiometer Tests. (optional tests) There are other units and methods of displaying vehicle IR data obtained by radiometry depending on individual test requirements.

a. Method. Make radiometer observations, when applicable, using an IR radiometer that measures radiance in the wavelength intervals of 2 to 20, 3 to 5, and 8 to 14 micrometers of the spectrum on a stationary vehicle operated under conditions b, c, and d of Table 1. Make measurements within 3 minutes of stopping the vehicle after the completion of the run shown in Table 1.

(1) Make the measurements in 360° azimuth every 45° starting at 180° rear view, and 180° in elevation at 45° or 30° intervals from front to rear and side to side on axis aspects. The ranges at which the measurements are made depend upon the field of view of the radiometer. Select the ranges so that at minimum range the projected field of view of the radiometer just encompasses the average dimension of the heated exhaust area. At maximum range the field of view should encompass the approximate size of the vehicle for front/rear observation and one-half the dimension of the side view. Side-view measurements will be identified by two readings, "front half" and "rear half." Data at ranges between maximum and minimum observation points may be selected as desired.

(2) Make the measurements in three standard wavelength bands: 2 to 20, 8 to 14, and 3 to 5 micrometers.

(3) To support each set of radiometer data, take a radiometer terrain background measurement of the following:

Terrain adjacent to vehicle.

Gravel road, dirt field, or sand area.

Grass/field area.

Tree area.

Horizon.

NOTE: For proper comparison, measurement of the background should be taken on the same day as and just prior to the test-item measurements.

(4) In addition to the range observations made at extended ranges from the target, a series of close-in survey readings are obtained under vehicle operating conditions b, c, and d of Table 1. The surface areas/vehicle components to be measured must represent various isothermal regions. The following are typical locations:

Exhaust outlet area Track skirt

Armor surrounding exhaust outlet area	Suspension
Air intake grilles	Hull, not associated with engine compartment
Air exit grilles	Turret
Armor surrounding engine compartment	Engine compartment external features

Table 1. Operating Conditions for Vehicle Signature Tests.

a.	Static solar exposure (pretest)	Expose vehicle, nonoperating, to outside ambient conditions for 24 hours before test.
b.	Static solar exposure	Expose vehicle, nonoperating, to outside ambient conditions and take measurements one hour prior to sunrise and at 3-hour increments until 3 hours after the sunset.
c.	Standard slow idle	After standard warmup,* position vehicle at test station to remain at idle (600 to 700 engine rpm) for 5 minutes before test observation.
d.	Standard fast idle (tactical idle)	After standard warmup,* position vehicle at test station to remain at fast idle (1200 to 1500 engine rpm) for 5 minutes before test observation.
e.	Standard slow operation	Move vehicle steadily at 8 km (5 mph) in low range or 1-2 gear for 5 minutes.
f.	Standard moderate-speed operation	Move vehicle steadily at 16 km (10 mph) in high range or high gear for 5 minutes.
g.	Standard high-speed operation	Move vehicle steadily at 32 km (20 mph) or 3/4 maximum red-line engine rpm for 5 minutes.

*Standard warmup: operation of vehicle 15 minutes over clockwise course and 15 minutes over counterclockwise course in high range or high gear at 16 to 32 km (10 to 20 mph) or 2000 to 2400 engine rpm. Additional 5 minutes' warming and in-transit time allowed to move vehicle from starting point to warm-up area.

b. Data required.

Type of Measurement[1]	Units of Energy	Apparent Temperature
Close-in survey data[2]	mW/(cm^2 x steradian) watts/steradian[3]	°C
Range data[4]	mW/(cm^2 x steradian)	ΔT°C[5]
Background data	mW/(cm^2 x steradian)	°C

[1]For each standard wavelength band.

[2]For each facet surface selected for observation.

[3]Apparent noncontrast. ("Watts/steradian" is a noncontrast term, representing the measurement of radiant flux itself and not a comparison of surface areas. Comparison of surface areas requires the measurement "mW/(cm^2 x steradian."))

[4]For projected field of view against target.

[5]Apparent temperature difference between test item and specified background.

4.1.2 Temperature Tests. (optional tests)

a. Method.

(1) Instrument the test vehicle with an on-board temperature-measuring system capable of acquiring temperature data via thermocouple or thermistor sensors. The area selected for thermocouple attachment is called a facet. Facets are selected to represent quasi-isothermal vehicle features and the thermal variations observed over the exterior of the vehicle by radiometer examination. Identify the facets by nomenclature and indicate surface area in square centimeters. The facets/components to be instrumented with sensors will correspond in general to the areas surveyed during the "close-in" radiometer test, paragraph 4.1.1a(4). Approximately 20 to 30 attachment points will be involved, with emphasis on the engine compartment area. In addition to temperatures at these points, record the following temperatures:

Ambient air	Compartment exit air at grille
Interior air, hull	Compartment intake air at grille
Exhaust gas	

(2) Since radiometer data are only representative of a standing vehicle under no-load conditions, the temperature data provide a means for predicting the vehicle signature under the operational conditions of e through g of Table 1. The temperature data are used as the basis for performing calculations converting temperature to radiance. Use the formula and emissivity factors, Appendix C, for this calculation. Of primary interest is the exhaust outlet area and associated "bright" thermal sources exterior to the vehicle and heated by engine exhaust transfer. Show results for the three standard wavelength bands in radiance and radiant intensity for indentified vehicle features of the exhaust networks or engine compartment.

b. Data required. Record temperatures (and time after operation the temperatures were taken) under the vehicle conditions stated in Table 1 for each sensor location.

4.1.3 Thermal Energy (Apparent Temperature) Distribution.

a. Method.

(1) Using an IR imaging system (Fig. 1), map the temperature of the entire vehicle under test. (Refer to Table 1, section b.) This test is usually conducted under a full diurnal cycle (24 hr). Measurements should be taken one hour prior to sunrise and at 3-hour increments until 3 hours after sunset in the spectral regions of 3 to 5 and 8 to 12 micrometers. Diurnal measurements should be made under weather extremes such as clear and overcast conditions, when practical.

(2) Obtain thermal imagery for the stationary vehicle conditions outlined in Table 1, conditions c and d, in 360° azimuth at cardinal points of 0°, 90°, 180°, 270° and vehicle top, and for background radiance in each wavelength. Imagery must be in a calibrated form since it is primarily required to assess the following vehicle signature traits:

Exhaust gas emission	High thermal contrast areas in engine compartment
Exhaust gas secondary heating	Heat leaks from engine compartment
Thermal conductivity from exhaust outlet area	Track and suspension
Areas of high on-board reflectivity	Vehicle exhaust outlet and grilles

(3) Repeat (2) for conditions e through g as outlined in Table 1, and assess any dynamic effects the vehicle imparts to the surroundings or any changes in the environment (dynamic test).

(4) Obtain thermal imagery for stationary vehicle conditions outlined in Table 1, conditions c and d, with vehicle at 45° to tree line, facing out, and 5 to 10 meters out from tree line. Record any changes to the environment imparted by the vehicle. Perform measurements from time zero to 5 or 10 minutes. In a semiarid or desert environment the background will be brush, sand dunes or other natural features.

(5) Repeat (4) with the vehicle in a tactical position inside the tree line.

(6) Obtain thermal imagery with a tactical sight such as the AN/TAS-4 or AN/TAS-6 for the TOW missile.

b. Data required.

(1) Apparent temperature of sources 1 and 2 (Fig. 2, 3-5 um range only).

(2) Apparent temperature of background (trees, foliage, sand, etc.).

(3) Meteorological data as specified in Appendix B.

(4) Apparent temperature across surface of vehicle and size of areas containing widely varying temperatures in °C.

(5) Thermal photographs of each view.

(6) Viewing range (i.e., 500 m, 1000 m).

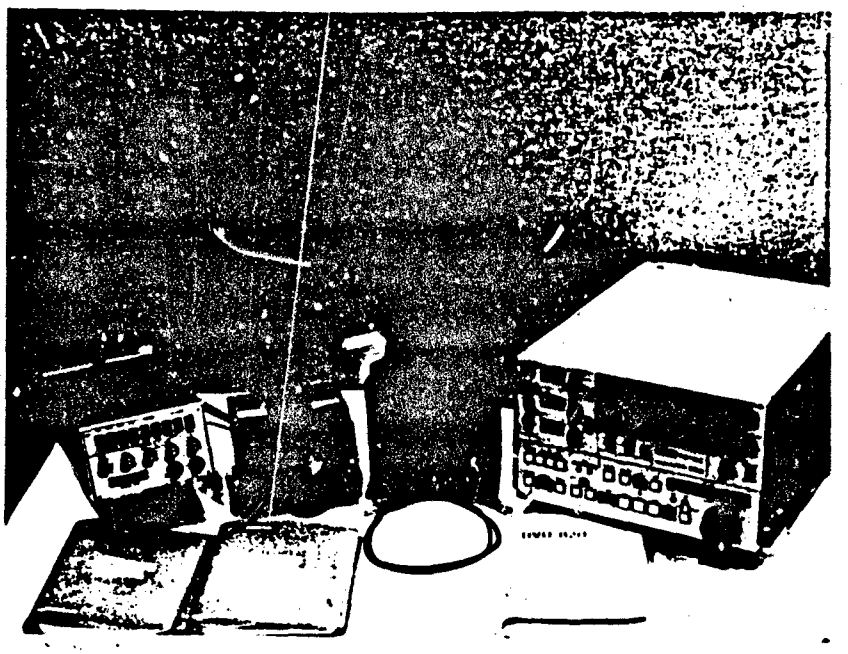
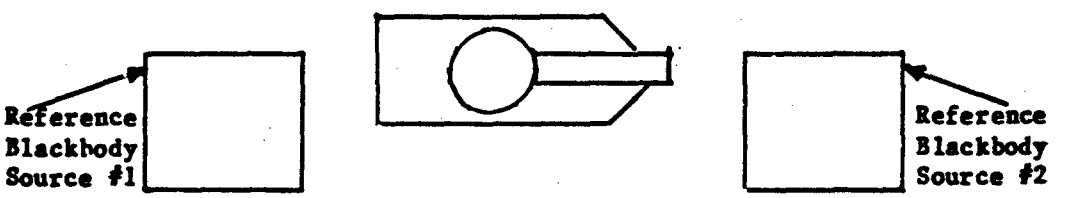
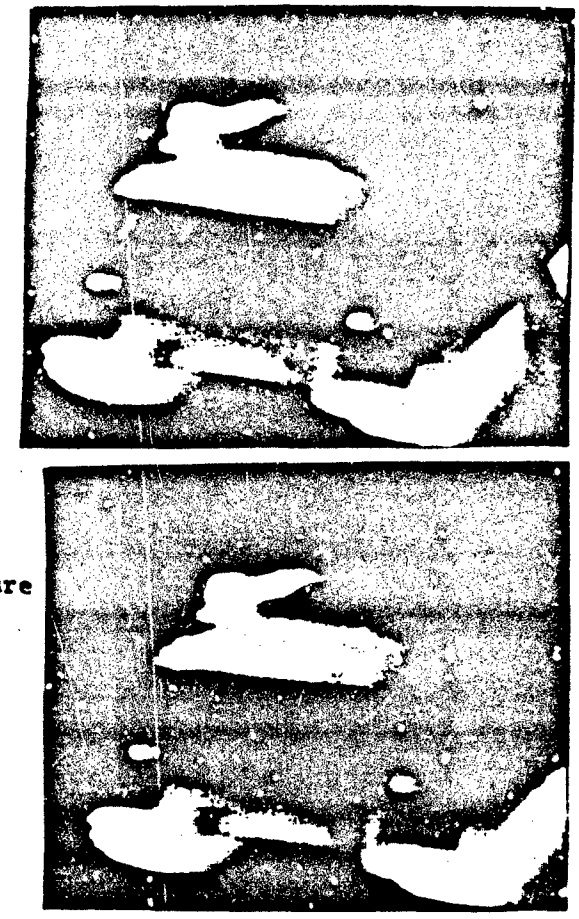


Figure 1. IR camera used to obtain thermal photographs in the 3- to 5- and 8- to 12-micrometer spectral region.



Reference Blackbody Source #1 should be near ambient conditions adjusted to the low end of isotherm scale. Reference Blackbody Source #2 should be adjusted to the high end of isotherm scale.

Figure 2. Test scenario for the 3- to 5-micron range.



a. Gray-scale view: overall temperature distribution (3- to 5-micrometer region).

b. Gray-scale view: overall temperature distribution (8- to 12-micrometer region).

Figure 3. Sample IR photography with gray-scale photograph (3- to 5- and 8- to 12-micrometer region).

4.1.4 Spectral Radiant Intensity. (optional test) Spectral radiant intensity, the fourth parameter needed for the optimal measurement of IR emission from a vehicle, is generally obtained using an interferometer or a spectral radiometer covering the 2- to 14-micrometer wavelength region.

a. Method.

(1) Operate the vehicle in accordance with condition d of Table 1, and take the view measurements for the parameter of interest as in the preceding test phases. (The typical spectral signature of the background and right side of a vehicle in the 3- to 5-micrometer region is shown in Fig. 4. A typical analysis of a vehicle, with data entries for the right side only, is shown in Fig. 5.)

(2) If required, evaluate the vehicle in the horizontal plane as well as a vertical plane, at the distance at which the vehicle fills the field of view of the measuring instrument.

(3) To obtain information about the temporal or spatial effects of warmup of a vehicle, use the measuring instrument at a single aspect of the vehicle. (Typical spectral signatures of the vertical back aspect - general exhaust location - are shown in Fig. 6. These begin with signatures of a cold vehicle and continue at intervals of one-half minute, 5 minutes, 30 minutes, and 2 hours after engine starts.)

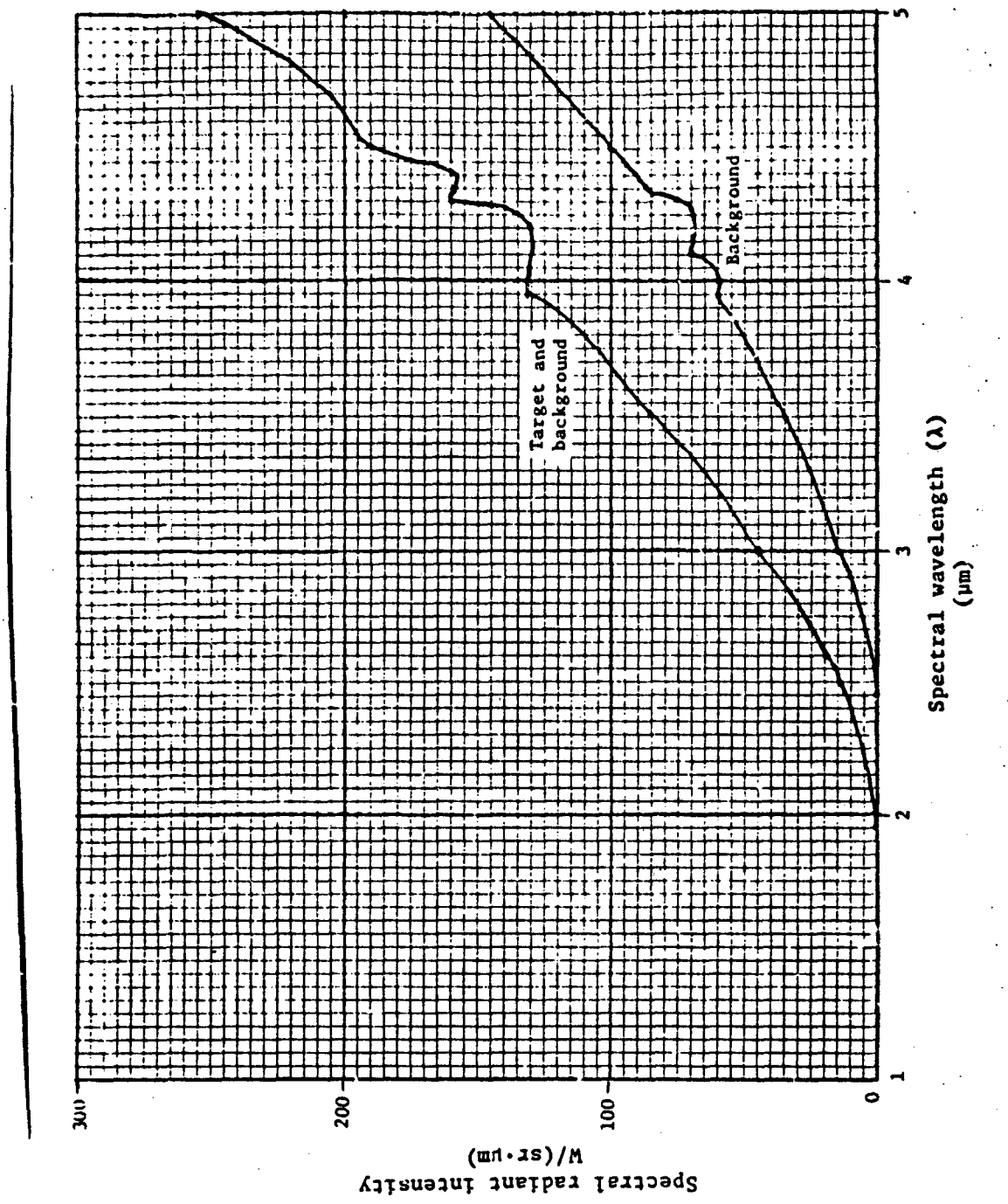


Figure 4. Spectral signature of vehicle (right side) and background in the 3- to 5-micrometer region of the IR spectrum.

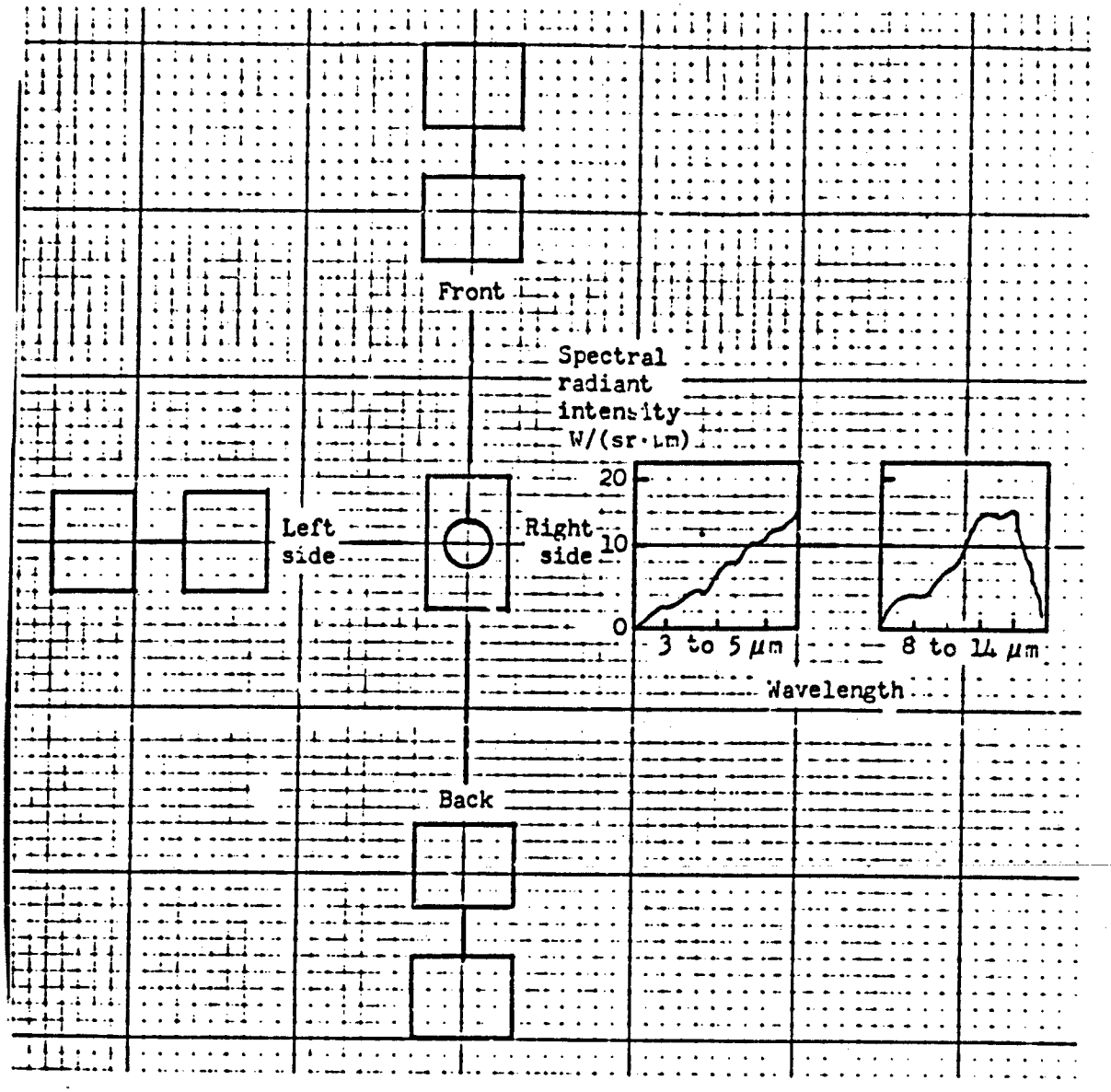


Figure 5. Spectral signature data for test vehicle at 100-meter distance in 3- to 5- and 8- to 14-micrometer regions.

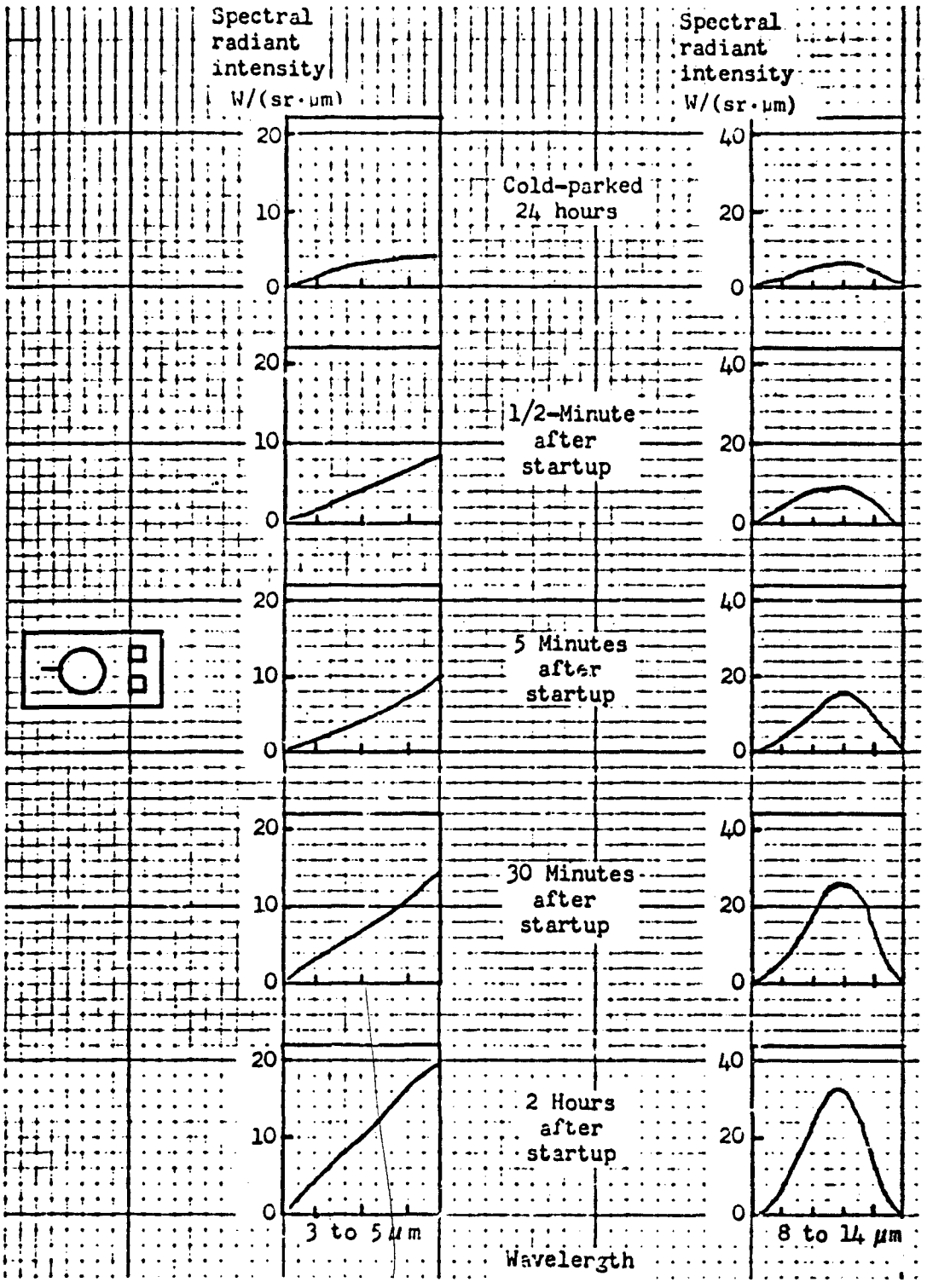


Figure 6. Variation in spectral energy output in the 3- to 5- and 8- to 14-micrometer regions as vehicle warms up.

b. Data required.

(1) Vehicle speed and time of start and finish of each operation over test course.

(2) Spectral radiant intensity of the vehicle at each aspect viewed.

(3) Time after operation that measurements were taken (e.g., 2 minutes after operation).

(4) Data as specified in Appendix B.

4.2 IR Temperature Measurements of Weapon Tubes. In addition to above, the actual surface temperature of the weapon tube may be measured using optical noncontact infrared thermometer or a contact thermocouple system. Spectral emissivity must be accurately known to evaluate absolute temperature range.

a. Method.

(1) Shortly after the weapon is fired, use the IR system to measure surface temperature on the tube. Starting at the base scan to the muzzle at a constant rate. (Typical temperature data-acquisition-system recording is shown in Fig. 7; the scale range covers a temperature span from 97.8° to 200° C.)

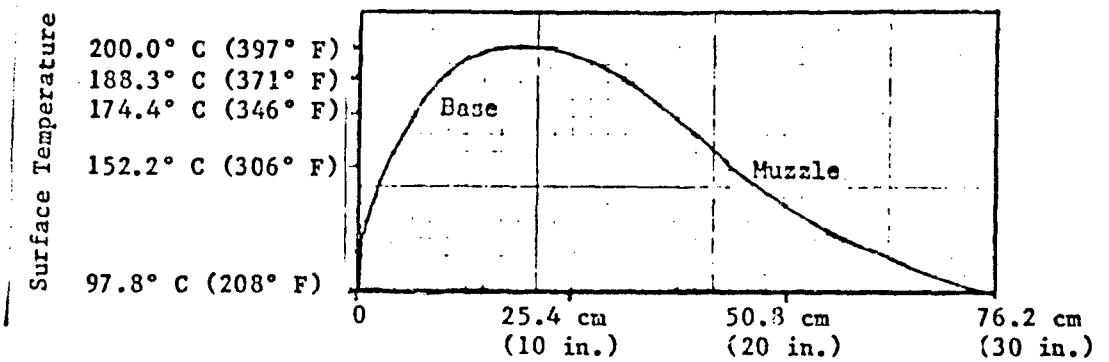


Figure 7. Typical record of surface-temperature scan of a representative mortar tube 2 minutes after firing.

(2) Thermocouple data in Figure 8 show the distribution of temperature at five different locations along a representative mortar tube 2 minutes after firing.

(3) Figure 9 shows a time history plot of the base temperature using liquid-nitrogen-cooled detectors in the 3- to 5-micron range (In Sb) and the 8- to 14-micron range (Hg Cd Te).

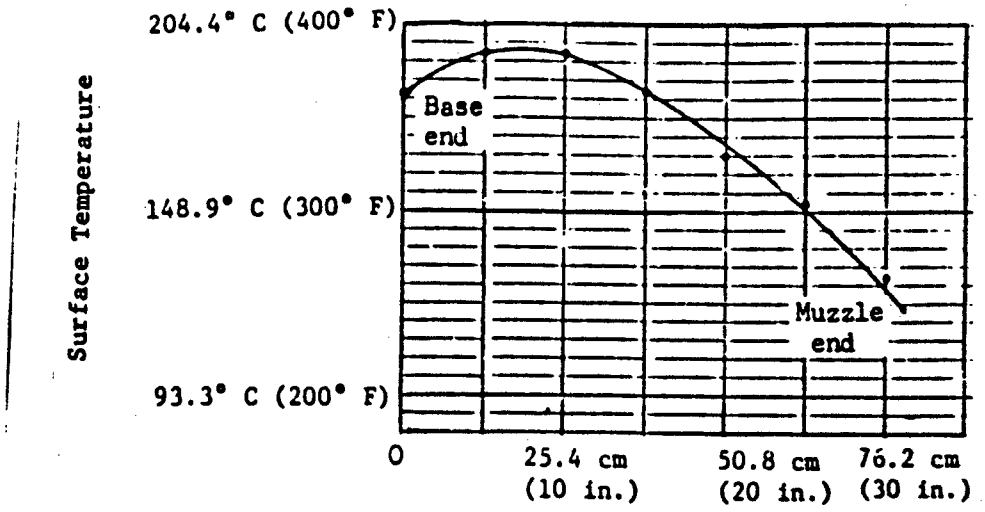


Figure 8. Temperature distribution along representative mortar tube at selected thermocouple locations after firing.

b. Data required.

(1) Temperature data as recorded.

(2) Thermocouple data, if taken, for comparison.

(3) Temperature record including scale range selected for the IR thermometer.

(4) Time after firing that measurements were taken (e.g., 2 minutes after firing).

5. PRESENTATION OF DATA.

5.1 Vehicle Signature. Imaging data should be presented in a hard-copy format with calibration in apparent temperature, °C. Radiometer data should be presented in tabular form containing apparent temperatures or radiance and contrast temperatures for specific backgrounds. Thermal imaging and radiometer data may be presented on polar plots to indicate radiant intensity (pointance) with the wavelength region used to perform the measurement. (These are not required data.)

5.2 Tube Temperature. The method used for the reduction and presentation of the tube temperature data obtained with the IR thermometer and how it is recorded is illustrated in paragraph 4.2.

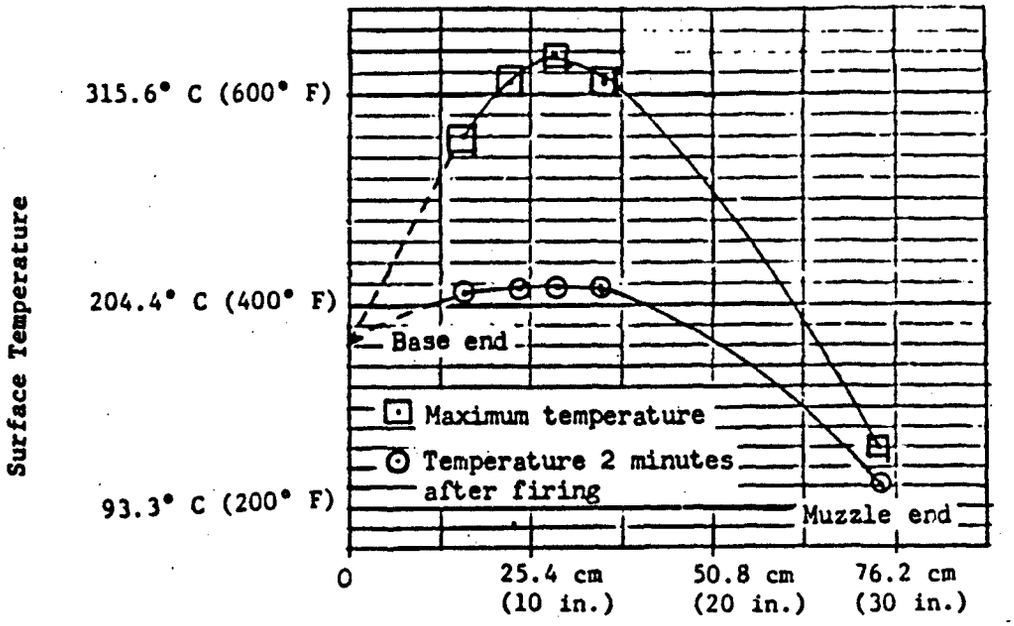


Figure 9. Peak surface temperature-time history of US Army 105-mm M102 Howitzer tube.

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APPENDIX A
GUIDE FOR TEST OPERATIONS CHECKLIST

Item	Yes	No	NA
1. Test parameters established.			
2. All operating personnel briefed on test requirements, special procedures, hazards, and any unusual aspects of test.			
3. All required instrumentation calibrated, properly installed, and operational.			
4. Safety requirements accomplished. (Checklist completed and SOP posted at test site.)			
5. Required data recorded.			
6. Other.			

APPENDIX B
DATA COLLECTION SHEETS

Record the following data and attach the documentation indicated as applicable.

B-1. Vehicle/Weapon Condition.

Vehicle/Weapon identification_____
Serial number_____
Date of manufacture_____
Tube size, model_____
Type of propellant/ammunition_____
_____

Odometer

Paint condition:*

a. New paint

b. Weathered

c. Imperfections

d. Base metal rust

Surface dust/dirt (See para 3.5c.)*

a. Clean

b. Dusty

c. Mud covered

d. Snow/frost/ice covered

e. Wet

Paint color

Mechanical condition:*

a. New

b. Normal

c. Noticeable malfunctions

d. Reduced power output

Kits

Speeds in gear

Engine identification

Direction of exhaust

Area of exhaust

Payload

Documentation:

Photographic survey

Drawing of engine compartment and exhaust area

Detailed dimensions of engine exhaust network and engine compartment

Speed versus rpm table

*Subjective observations.

B-2. Climatic Support Data.

Date

Location

Air temperature

Relative humidity

Ground/terrain description

Tree description

Sun elevation

Rainfall rate

Rainfall total

Cloud cover

Sky condition

Visibility

Wind speed/direction

Absolute solar load

B-3. Test Course/Firing Range Description.

B-4. Instrumentation (nomenclature, description, location, calibration).

B-5. Test Data (list of inputs for plot, graphs, photographs).

APPENDIX C

COMPUTATION OF RADIANCE FROM AN OBJECT AT A GIVEN TEMPERATURE

Where radiance (N) is to be calculated for a given temperature (T), its value is given as:

$$N = \frac{\varepsilon \sigma T^4}{\pi} = W/(cm^2 \times sr)$$

where: ε = emissivity. (See Table C-1 below.)
σ = Stefan-Boltzmann Constant [$5.672 \times 10^{-12} W/(cm^2 \times T^4)$].
T = temperature of material (°K).

NOTE: For a comprehensive evaluation of radiance and radiant energy, the reader is referred to "The Infrared Handbook," Wolfe and Zissis, Chapters 1 and 5.

Table C-1. Emissivities of Various Materials.

Material	Emissivities (ε) 2 to 20 um	3 to 5 um	8 to 14 um
18-8 weathered stainless	0.57	0.40	0.49
24-ST weathered aluminum	.26	———	———
18-8 polished stainless	.12	———	———
Pinewood	.90	———	———
Cast iron	———	———	———
Oxidized mild sheet steel	———	———	———
Red iron oxide	———	———	———
Soot	———	.99	.99
White enamel	———	———	.90
OD paint (MIL-E-46117)	———	.74	.72
Grass	———	.82	.88
Sand, silt loam	———	.85	.94
Coniferous	———	.96	.97
OD paint (TT-E-529)	.90	———	———
Rubber	.91	———	———
Oxidized paint	.97	———	———

Selected Emissivities (no wavelength)

Painted armor, fresh, clean	.91
Painted armor, weathered	.93
Rubber (track block-road wheels)	.87
Canvas	.93
MIL-E-52798 all colors	.85 to .94

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